

**INDUCTION HEATING SYSTEM FOR  
REDUCED SWITCH STRESS**

**Technical Field**

The present invention relates generally to an induction heating system and more particularly to an induction heating system utilizing a pulse initiator to provide efficient heating with minimal switch stress.

**Background of the Invention**

The term "induction heating" generally describes a process in which an alternating current is passed through a coil to generate an alternating magnetic flux. When the coil is placed in close proximity to or wrapped around a metallic object that is to be heated, the alternating magnetic flux inductively couples the load to the coil and generates eddy currents within the metallic object causing it to become heated. Because of its function, the coil is often referred to as a "work coil" or "induction head," and the metallic object to be heated as a "load." Induction heating may be used for many purposes including curing adhesives, hardening of metals, brazing, soldering, welding, and other fabrication processes in which heat is a necessary agent or catalyst.

The field of induction heating is considered to be well-established, with several types of induction heating systems having been developed to control power delivered to the induction head and, thus, the heat produced in the load. One type of induction heating system, sometimes referred to as a resonant system, generally comprises a power supply, a resonant induction head typically formed by the work coil and a capacitor, and some type of switching means to control delivery of power to the resonant induction head by the power supply. Generally, the switching means is closed to cause the power supply to provide a current to the resonant induction head resulting in energy being stored in the work coil. When the switching means is opened, the induction head begins to resonant and generate an oscillating voltage and corresponding oscillating current, and the stored energy is discharged to the load as heat.

The greatest amount of energy is transferred from the induction head to the load during the first half-cycle of oscillation. Thus, to provide the quickest and most efficient heating of loads, conventional induction heating systems are often configured to replenish

the stored energy to the induction head by operating the switching means when the oscillating voltage reaches zero at the end of the first half-cycle. However, this often does not coincide with a zero voltage at the switching means resulting in potential stress to the switching means, or requires complicated switching means to do so.

5 Induction heating systems, particularly those employing resonant induction heads, would benefit from a simplified scheme that substantially minimizes stress to the switching means while still providing quick and efficient load heating.

### **Summary of the Invention**

10 The present invention provides an induction heating system. The induction heating system comprises a power switch, a resonant heating circuit, and a pulse initiator. The resonant heating circuit is configured to generate an oscillating voltage in response to a DC pulse input. The pulse initiator is positioned across the power switch and configured to monitor a voltage across the power switch and to initiate application of a subsequent  
15 DC pulse to the resonant heating circuit upon detecting a substantially zero voltage across the power switch during a first cycle of the oscillating voltage.

### **Brief Description of the Drawings**

The accompanying drawings are included to provide a further understanding of the  
20 present invention and are incorporated in and constitute a part of this specification. The drawings illustrate the embodiments of the present invention and together with the description serve to explain the principals of the invention. Other embodiments of the present invention and many of the intended advantages of the present invention will be readily appreciated as the same become better understood by reference to the following  
25 detailed description when considered in connection with the accompanying drawings, in which like reference numerals designate like parts throughout the figures.

Figure 1 is a block diagram illustrating one exemplary embodiment of an induction heating system according to the present invention.

Figure 2 is a schematic and block diagram illustrating one exemplary embodiment  
30 of an induction heating system according to the present invention.

Figure 3 is an exemplary graph of the voltage across a power switch of an induction heating system according to one embodiment of the present invention.

### **Detailed Description**

In Figure 1, an induction heating system in accordance with the present invention is generally indicated at 20. Induction heating system 20 includes a rectifier 22, a resonant heating circuit 24, a power switch 26, a pulse controller 28, and a pulse initiator 30. Induction heating system 20 is configured to be inductively coupled at 32 to an external electrically conductive load 34 and operates to control the switching of power switch 26 so as to provide substantially maximum heating of load 34 while concurrently substantially minimizing switching stress of power switch 26.

Rectifier 22 is connectable to an A/C power source 36 via a first input node 38 and a second input node 40, and is configured to provide a DC voltage level at an output node 42. Resonant heating circuit 24 is coupled between rectifier output node 42 and a node 44, and power switch 26 is coupled between node 44 and a ground node 46. Pulse controller 28 is configured to provide a switch control signal to power switch 26 via a path 48 to cause power switch 26 to first close and then, after a predetermined duration, to open to thereby provide a DC pulse to resonant heating circuit 24. The predetermined duration is based on a maximum energy value that resonant heating circuit 24 can store without sustaining damage. Resonant heating circuit 24 generates an oscillating voltage and an associated oscillating current and alternating magnetic flux in response to the DC pulse to thereby to heat inductively coupled external load 34.

Pulse initiator 30 is coupled in parallel with and configured to monitor a voltage across power switch 26. Pulse initiator 30 is further configured to provide a pulse initiation signal to pulse controller 30 via a path 50 to cause pulse controller 25 to initiate application of a subsequent DC pulse to resonant heating circuit 24 when a voltage across power switch 26 is substantially equal to zero during a first cycle of the oscillating voltage. By closing power switch 26 when the voltage across power switch 26 is at substantially equal to zero during the first cycle of oscillating voltage, induction heating system 30 according to the present invention both substantially maximizes the heating of external load 34 and substantially minimizes switching stress of power switch 26.

Figure 2 is a schematic and block diagram 60 illustrating one exemplary embodiment of induction heating system 20 according to the present invention. Rectifier 22 is a standard diode bridge rectifier comprising four diodes 62, 64, 66, and 68. First

diode 62 has an anode coupled to first input node 38 and a cathode coupled to output node 42. Second diode 64 has an anode coupled to second input node 40 and a cathode coupled to output node 42. Third diode 66 as an anode coupled to ground 46 and a cathode coupled to first input node 38. Fourth diode 68 has an anode coupled to ground 46 and a cathode coupled to second input node 40. Rectifier 22 is connectable to external A/C supply 36 and configured to provide a DC voltage level at output node 42.

Resonant heating circuit 24 comprises a resonant capacitor 70 and a working head 72 comprising an inductive heating coil 74 wrapped around a ferrite core 76. Resonant capacitor is coupled in parallel with inductive heating coil 74 and has a first terminal coupled to rectifier output node 42 and a second terminal coupled to node 44. Resonant heating circuit 24 generates an oscillating voltage and an associated oscillating current and alternating magnetic flux in ferrite core 76 in response to a DC voltage pulse to thereby to heat inductively coupled external load 34. In one embodiment, working head 72 is coupled to resonant capacitor 70 using flexible leads that enable working head 72 to be moveable with respect to inductive heating system 20 and to be placed in contact with remote loads that are to be heated, such as load 34. In one embodiment, working head 72 does not include a ferrite core 76.

Power switch 26 comprises an insulated gate bipolar transistor (IGBT) having a gate 80, a collector 82 coupled to node 44, and an emitter coupled to ground 46. In other embodiments, power switch 26 comprises a field effect transistor (FET), a bipolar junction transistor (BJT) , or a silicon controlled rectifier (SCR). Pulse controller 28 is configured to provide a switch control signal to power switch 26 via path 48 to cause power switch 26 to first close and then, after a predetermined duration, open to thereby provide the DC voltage pulse to resonant heating circuit 24. The predetermined duration is based on a maximum energy value that resonant heating circuit 24 can store before sustaining damage. Pulse controller 28 is configured to close power switch 26 after initial power-up of induction heating system 20 to thereby initiate a first DC voltage pulse to resonant heating circuit 24, and to thereafter close power switch 26 to initiate subsequent DC voltage pulse to resonant heating circuit 24 based on receipt of the pulse initiation signal via path 50 from pulse initiator 30.

Pulse initiator 30 is coupled in parallel with power switch 26 and comprises a voltage divider 90 and a level switch 92. Voltage divider 90 comprises a dropping resistor

94, a monitoring resistor 96, and a plurality of diodes 98. Dropping resistor 94 has first terminal coupled to node 44 and a second terminal coupled to a monitoring node 100. Monitoring resistor 96 is coupled between monitoring node 100 and ground 46. The plurality of diodes 100 are series connected cathode-to-anode and coupled in parallel with monitoring resistor 96 with an anode of a first diode of the plurality coupled to monitoring node 100 and a cathode of the last diode of the plurality coupled to ground 46, and function to limit a voltage across monitoring resistor 96 to a maximum level.

When power switch 26 is in a closed position, node 44 is brought to ground which effectively removes pulse initiator 30 from the system while a DC voltage pulse is being applied to resonant heating circuit 24. When the DC voltage pulse is removed from resonant circuit 24 by opening power switch 26, resonant heating circuit 24 begins to generate an oscillating voltage. The sum of the DC voltage level at DC output node 42 and the oscillating voltage generated by resonant circuit 24 is present at node 44, or collector 82, to ground 46, and is hereinafter referred to as  $V_C$  (voltage at collector 82 to ground). When resonant heating circuit 24 is generating the oscillating voltage,  $V_C$  appears as an oscillating waveform having a DC offset substantially equal to the DC voltage level at DC output node 42.  $V_C$  is also present across dropping resistor 94 and monitoring resistor 96 of voltage divider 90, with the majority of the voltage appearing across dropping resistor 94 and a monitoring voltage appearing across monitoring resistor 96 from monitoring node 100 to ground 46. As  $V_C$  oscillates, so does the monitoring voltage across monitoring resistor 96.  $V_C$  is further illustrated in graphical form below by Figure 3.

Level switch 92 is an inverting complimentary metal oxide semiconductor (CMOS) Schmitt trigger 102 having an input 104 coupled to monitoring node 100 and receiving the monitoring voltage, and an output 106 coupled to pulse controller 28 via path 28. Schmitt trigger 102 is configured with hysteresis so as to have a low voltage set-point and a high voltage set-point. Schmitt trigger 102 is configured to compare the monitoring voltage to the low and high voltage set-points and to provide at output 106 the pulse initiation signal causing pulse controller 28 to initiate application of a subsequent DC pulse to resonant circuit 24 when the monitoring voltage is substantially equal to low voltage set-point. In one embodiment, the low voltage set-point is a predetermined value incrementally greater than zero, such that when taking into account inherent propagation

delays involved in pulse initiator 30 providing the pulse initiation signal to pulse controller 28 and pulse controller 28 providing the switch control signal to power switch 26, power switch 26 actually closes when the monitoring voltage, and thus  $V_C$ , has a value substantially equal to zero.

Figure 3 is an exemplary graph 120 of the voltage across power switch from the collector 82 to ground, hereinafter referred to as  $V_C$ , and is included to aid in describing the operation of induction heating system 20. At time  $t_0$ , with no A/C source applied to first and second input nodes 38 and 40,  $V_C$  is equal to zero, as indicated at 122. At time  $t_1$ , as indicated at 124, A/C supply 36 is applied across first and second input nodes 38 and 40, resulting in rectifier 22 providing a DC voltage level ( $V_{DC}$ ) and producing a DC voltage substantially equal to  $V_{DC}$  from collector 82 to ground 46. After the initial power-up of induction heating system 20, pulse controller 28 is configured to provide a power switch control signal to gate 80 via line 110 to cause IGBT 78 to become forward-biased and pull collector 82 to ground 46 via emitter 84, as indicated at time  $t_2$  at 126. Pulse controller 28 is configured to maintain IGBT 78 in a forward-biased condition for a duration ( $\Delta t$ ) 128 from  $t_2$  to time  $t_3$ . During this duration, collector 82 is shorted to ground 46 via emitter 84, resulting in a DC voltage pulse having a magnitude substantially equal to  $V_{DC}$  and duration of  $\Delta t$  to be applied across resonant heating circuit 24 and causing a charge to accumulate in inductive coil 74. The duration  $\Delta t$  128 determines the magnitude of the accumulated charge in inductive coil 74.

At time  $t_3$ , as indicated at 130, pulse controller 28 provides a power switch control signal to gate 80 to cause IGBT 78 to become reverse-biased causing IGBT 78 to no longer conduct to ground and thereby terminate the DC voltage pulse to resonant circuit 24. At  $t_3$  130, inductive coil 74 begins to discharge into resonant capacitor 70 and resonant heating circuit 24 begins generating an oscillating voltage which in-turn generates a corresponding oscillating flux in ferrite core 76 to heat external load 34. The oscillating voltage generated by resonant heating circuit 24 combines with  $V_{DC}$  to form an oscillating voltage having a DC-offset substantially equal to  $V_{DC}$  across power switch 26 from collector 82 to ground 46, as indicated at 132. If no additional DC pulses are applied to resonant heating circuit 24, the oscillating waveform across power switch 26 would gradually decay, or "ring-out," around the DC-offset as indicated by the dashed waveform 136.

However, when power switch 26 is opened at  $t_3$  130, voltage  $V_C$  is provided from node 44 to ground 46 and thus, across dropping resistor 94 and monitoring resistor 96 and thereby providing the monitoring voltage ( $V_{MON}$ ) at input 104 of CMOS Schmitt trigger 102. As  $V_C$  rises from a value of substantially zero volts at  $t_3$  130 to a peak value 138, the voltage across monitoring resistor 96 rises, but is limited to a maximum value as dictated by limiting diodes 98. As  $V_C$  passes peak value 138, the value of  $V_C$  drops to point where limiting diodes 98 are no longer forward-biased and dropping resistor 94 and biasing resistor 96 function as a conventional voltage divider.

$V_C$  continues to drop until, at time  $t_4$  at 140, it reaches an initiation voltage level ( $V_I$ ), as indicated at 142, at which point  $V_{MON}$  at input 104 is substantially equal to the low-voltage set-point of Schmitt trigger 102. When  $V_{MON}$  is substantially equal to the low-voltage set-point, Schmitt trigger 102 provides at output 106 a pulse initiation signal to pulse controller 28 via path 50 causing pulse controller 28 to provide a switch control signal to gate 80, which in-turn causes IGBT 78 to close to thereby initiate a subsequent DC pulse to resonant heating circuit 24. Pulse controller 28 maintains IGBT 78 in a forward-biased condition for a second duration ( $\Delta t$ ), indicated at 144, from  $t_4$  140 to  $t_5$ , indicated at 146, to thereby apply the subsequent DC pulse to resonant heating circuit 24. The above described process is then repeated as necessary to heat load 34, resulting in  $V_C$  having a voltage waveform comprising a series of peaks as indicated by peaks 138 and 148.

Numerous characteristics and advantages of the invention have been set forth in the foregoing description. It will be understood, of course, that this disclosure is, and in many respects, only illustrative. Changes can be made in details, particularly in matters of shape, size and arrangement of parts without exceeding the scope of the invention. The invention scope is defined in the language in which the appended claims are expressed.